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AUTONOMOUS HYBRID TRACTOR UNIT WITH A PREDICTIVE CONTROL SYSTEM

LEZHNEV. L. YU, KOROTKOV. V. S, PETRICHENKO. D. A & PAPKIN. B. A

Moscow Polytechnic University, Moskva, Russia

ABSTRACT

Electric drive of traction wheels has become an increasingly familiar phenomenon in the sphere of passenger car transportation. However, it is likely an exception for heavy trucks, where fuel economy is also important. For this reason, the development of economical freightage capacities using modern electrote chnical and information technologies is a relevant objective. One of the possible areas of research aimed at increasing the efficiency of a hybrid electric vehicle is the use of a predictive control system. This system can predict energy costs, which are required to overcome a given route, and, based on these data, optimize energy consumption during its activity. This paper describes the initial stage of the development of a modern hybrid truck with the possibility of automatic movement on a guided path. The article gives the description of the concept, construction and contents of an autonomous hybrid tractor unit along with its properties. The structure of the predictive control system presented in the paper reflects the feature of the system of predictive control itself, and its interaction with other units of the vehicle.

KEYWORDS: Predictive Control, Control Strategy, Hybrid Electric Vehicle, Tractor Unit & Internal Combustion Engine

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INTRODUCTION

According to the International Organization of Motor Vehicle Manufacturers (OICA), the total sales of cars in the world amounted to almost 97 million in 2017, including about 26 million commercial motor vehicles [1]. Thus, market growth ranged from 2% to 6.4% in 2011-2017 (Figure 1)

Figure 1: Volumetric Capability of the World Commercial Transport Market in 2005-2017 1

At the same time, sales of plug-in hybrid electric vehicles (PHEV) in the automotive sector reached 1.2 million (Figure 2). This means that their share exceeded 1.5% [2], maintaining the growth rates of more than 50%

per year. The last forum of The Electric Vehicles Initiative (EVI) stated a 30% share of the electric vehicles in the total market of passenger cars, light commercial vehicles, buses and trucks. Considering the current growth of the sales of electric and hybrid vehicles that aim seems to be definitely achievable. The members of EVI include the representatives of different countries that produce more than 95% of all electric vehicles all over the world.

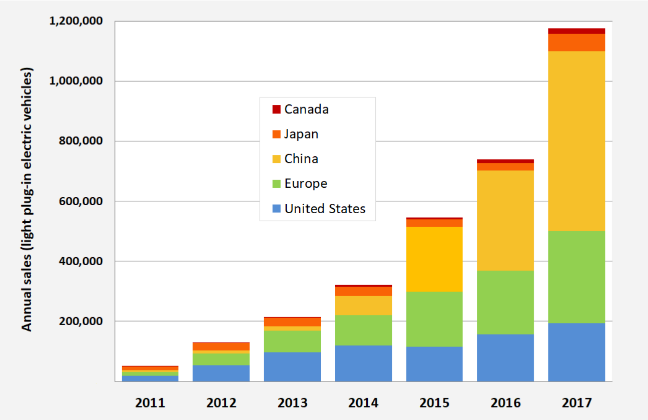

Figure 2: Global Annual Sales of Light-Duty Plug-in Electric Vehicles in Top-Selling Markets (2011-2017) 2

The main problem of the low abundance of electrically driven motor transport is its low autonomy, i.e. small, relative to vehicles driven by an internal-combustion engine, fuel distance. One of the possible areas of research aimed at increasing the efficiency of a hybrid electric vehicle is the use of a predictive control system (PCS). This system can predict energy costs, which are required to overcome a given route, and, based on these data, optimize energy consumption during its activity.

Most works, devoted to PCS, consider human-operated vehicles. Often, it is proposed, for example, to model a future power request from the driver as Markov chain [3], [4], use dynamic programming techniques [5] or apply the theory of stochastic processes in order to analyze the power unit operation [6], [7].

Co-use of autopilot and PCS will significantly reduce the impact of random events on the energy consumption of the vehicle, because the uncertainty introduced by the driver’s actions is excluded [8], [9]. An autonomous vehicle with a PCS may not only calculate in advance the optimal modes of operations of the power unit for each point of a given route, but also stick to the applied control strategy [10].

Taking into account the above-mentioned ideas, we can conclude about the development of autonomous vehicles with hybrid traction; PCS lays on the edge of modern automotive technologies.

THE CONCEPT OF THE DEVELOPED VEHICLE

This paper considers the design of the operated hybrid autonomous tractor unit.

In general, a PHEV power unit contains one or more electrical machines, internal combustion engine, energy storage (battery), fuel tank and charger device. Depending on the type of the power unit (serial, parallel, power-split), it might contain additional elements. The ability to move using electrical energy, which is supplied to the battery from an external source, can significantly reduce operating costs, which has a positive effect on the popularity of PHEV.

Autonomous cars can move without human support. They can use a variety of tools to control the actual environment, such as radar, lidar, navigation systems, speed and acceleration sensors and computer vision. One of the most discussed advantages of an autonomous vehicle is a potentially significant reduction in the number of road accidents. Besides, autonomous vehicles provide reduced energy consumption compared to regular ones, due to the use of more effective movement modes. Co-use of the automated motion and hybrid engine power unit will give an even greater reduction in exploitation costs. Research and development concerning autonomous vehicles are conducted in many different areas, but trucks are considered much rarer than regular passenger vehicles.

According to the U.S. Energy Information Administration International Energy Outlook 2016 [11], about 22% of all transport energy costs accounted for trucks in 2012. Thus, even a small increase in freight efficiency can bring significant economic benefits. One of the most common modifications of medium and heavy trucks is a tractor unit. This tractor unit is designed to work with semi-trailers, which are attached to the tractor with fifth-wheel coupling. The main advantages of the tractor unit are high capacity, high load capacity-to-weight ratio and improved maneuverability.

As an example of an autonomous tractor unit, one can consider the project of a student of the Moscow Polytechnic University [12]. Figure 3 shows the view of an unmanned tractor unit, as well as a road train in whole.

Figure 3: An Example of the Autonomous Tractor Unit 12

The main objective of the PCS under development is, to optimize modes of operations of the power unit, in order to reduce energy consumption when driving on a given or intended route. In order to improve the accuracy of simulation of all vehicle systems at driving along the route, it is required to take into account a large number of factors. The factors include external environment (terrain, trajectory, weather, traffic, etc.) and parameters of particular subsystems of the power unit (efficiency and its change in terms of temperature mode, etc.).

While moving on the specified route, the predicted conditions may change. Therefore, the developed system should not only respond quickly to the new external conditions, but also change the parameters of the calculation model to achieve the main goal– energy costs minimization. Besides, it is possible to note the problem of optimization of regenerative braking. To increase the share of the recuperated energy, the PCS can determine the best deceleration strategy to ensure the most efficient operation of the motor and batteries, according to the current road situation. The strategy should take into account not only the rotor speed of the motor and the required torque but also the current state of charge (SOC) of the battery and its temperature.

Taking into account GPS data, the PCS can automatically exclude the use of an internal combustion engine for charging batteries in special areas with environmental restrictions.

DESIGN OF AN AUTONOMOUS HYBRID TRACTOR UNIT

A hybrid autonomous tractor unit, which preliminary layout is shown in Figure 4, has a spar-type frame, independent front suspension and dependent rear suspension with leaf springs. Spar-type frame vehicle, which is very traditional for cargo transport vehicles, provides sufficient rigidity. The frame bears all the main hybrid power unit components such as traction drive, batteries and motor-generator set. The developed design of a hybrid autonomous tractor unit without external body parts is shown in Figure 4.

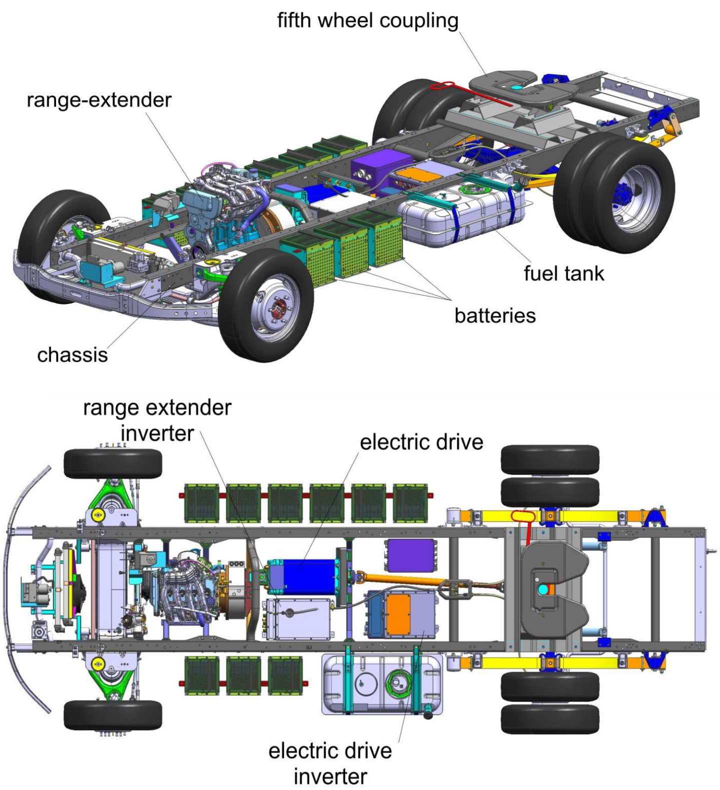

Figure 4: Layout of the Hybrid Autonomous Tractor Unit

The structure of the motor-generator in addition to the internal combustion engine includes, electric drive consisting of a synchronous machine with permanent magnets powered by the control inverter. The inverter is connected to the vehicle's Direct Current (DC) bus. The motor-generator electric drive operates in the motor mode to start it up, and in the generator mode, while generating electrical energy to charge the batteries.

The traction drive contains a power inverter and an asynchronous electric machine. It scard an shaft is connected to the main gear and drive wheels. The drive converts electrical energy into mechanical during acceleration and movement at a given speed. Under braking, it recuperates mechanical energy back into electrical.

Electrical energy is stored in air-cooled lithium-ion batteries, located along the sides of the vehicle and connected to a common DC bus.

In addition, there are two separate cooling systems for the internal combustion engine and power electric equipment. Moreover, the designed autonomous tractor unit contains electromechanical steering rack and hydraulic

braking system, with the possibility of electronic control of the braking force on each wheel separately and the fifth wheel coupling device for connection to the semi-trailer.

STRUCTURE OF THE PCS

The functional diagram of the PCS under development is shown in Figure 5. Definitely, the PCS must solve the task of optimization of the energy consumed over the specified route. It must take into account the terrain relief on a given route, as well as the road situation, weather conditions and additional factors. Another important task is, to minimize the use of an internal combustion engine in settlements, in order to reduce the negative impact of exhaust gases on the environment.

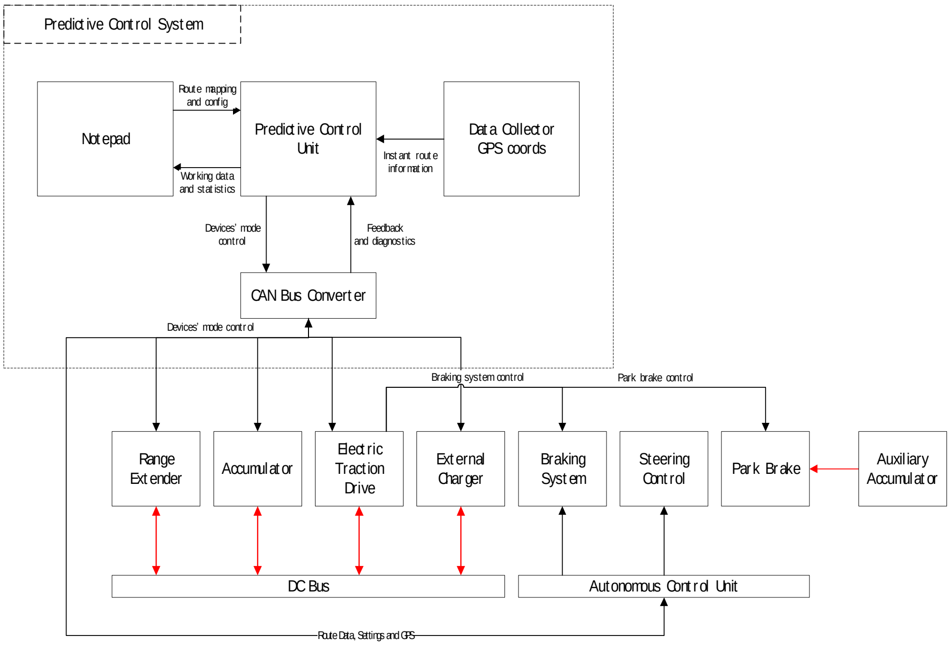

Figure 5: Functional Diagram of the PCS Under Development

As already shown in [12], in order to build the route and set up control parameters of the power unit and PCS, the vehicle must contain a device with a user interface. In the above-presented figure, the Notepad, running specialized software, plays this role. Predictive control unit receives information from both the user and the data collection and geo-positioning systems. According to the obtained data and control parameters, the PCS builds the strategy of the hybrid vehicle power unit control. Two Communication Area Network (CAN) buses are used to control different onboard devices. The predictive control unit controls the operating modes of energy sources and consumers using CAN bus “Devices’ mode control”. The second isolated CAN bus is used to control the brake system. The Park Brake control unit has its own control system and an additional Auxiliary Accumulator. That functionality provides a safe stop and prevents the vehicle of unexpected movement in case of failures in other subsystems.

The Autonomous Control Unit allows controlling the vehicle in the autonomous mode for a given route. The development of this unit is not the purpose of this work. As a part of the current development, it will allow an operator to remotely control the steering, traction drive and brake system for maneuvering or maintenance.

The developed system provides the possibility of building several routes to the destination point and the selection of the optimal one, according to the given criteria. The main criterion, as it has already been said, is to reduce energy

consumption. On the other hand, the developed system allows changing the target criterion: the minimization of delivery time or tractor run can be selected. In all those cases, the optimal schedule of energy consumption and the most effective modes of operation of the individual components of the power unit are calculated.

During the movement of the hybrid tractor over the selected route, the battery's SOC is regularly compared with pre calculated values. This allows the system to perform quick adjustments in the simulation that reflect the current technical condition of the vehicle or previously unaccounted external factors. Moreover, the traffic situation and weather data is updated, allowing changing the route (if necessary) or the control schedule of the power unit.

CONCLUSIONS

As shown in the paper, electrically driven vehicles take a growing share in the global automotive market. Statistically, passenger vehicles form most of the modern electric and hybrid vehicles, while trucks continue using traditional internal combustion engines. The use of a hybrid power train with a PCS will significantly reduce the energy consumption of trucks, which form one-fifth of all transport energy costs.

The developed design of the autonomous hybrid tractor unit will allow performing the adjustment and testing of the PCS of an autonomous vehicle. This system is able to calculate the optimal route to the destination and adjust the operating parameters of the vehicle power unit in motion. The optimization of the power unit control strategy takes into account a wide range of external factors: environmental (terrain, trajectory, weather, traffic, relief, etc.) and the current state of the particular subsystems of the vehicle power unit (efficiency factors and their change in terms of temperature mode, etc.).

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